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Influence of the structural and functional characteristics of the seeding material on the yield structure elements and resistance to leaf diseases of spring soft wheat

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Abstract. The high-quality grain use when sowing is a necessary condition for obtaining a high yield. Along with the standard tests regulated by the ISTA (International Seed Testing Association), there are promising introscopic techniques for the seed material quality controlling - methods of microfocus radiography and gas discharge visualization (electrophotography). The effect of structural and functional characteristics of the seeding material on the wheat productivity and diseases resistance was studied out on the experimental field of the Vavilov All-Russian Institute of Plant Genetic Resources. Ten accessions of soft wheat with the 'parametric passport' (including more than thirty optical parameters, including gas discharge images, morpho- and densitometric analysis of X-ray patterns) were used as an experimental seeding material. Unviable wheat seeds, in comparison with healthy ones, were characterized mainly by a smaller area, form coefficient, standard deviation of three-dimensional fractality by isoline, entropy by isoline, higher brightness and standard deviation of the isoline radius of the gas discharge images. Morpho- and densitometric indices of unviable seeds differed in reduced values of the circle factor, roundness, minimum and maximum average brightness, but in greater elongation and optical density of the X-ray patterns projection. The intensity of wheat affection by diseases has varied depending on the structural and functional characteristics of seeds. It was noted, that the brown rust development decreased with an increase in the entropy by isoline, the contour irregularity and the average radius of the isoline.

Key words: disease resistance, gas discharge imaging, microfocus radiography, seed material, soft wheat, yield structure.

INTRODUCTION

The environmental safety of food production is one of the main requirements for agricultural products in modern conditions of the global agro-industrial sector. In Russia the concept of agricultural production development are revising and shifting it towards reducing the external anthropogenic impact on agrocenoses and creating favorable conditions for realizing their own potential (Pavlyushin & Lysov, 2019).

Smart farming system - this is an innovative technology that helps to improve the quality and quantity of agricultural products in the country (Bharath et al., 2020). A necessary condition for obtaining high yields of wheat and improve its quality is use complete grain when seeding (Šramkováa et al., 2009; Shpilev et al., 2018; Ricachenevsky et al., 2019). At the same time, the seed material is often of poor quality now. The part of grain crops' substandard seeds can reach up by 40% (Arkhipov et al., 2013a). In this regard, there are a number of standard tests regulated by ISTA (International Seed Testing Association), as well as promising introscopic methods for seed quality control (Pearson et al., 2007; Huang et al., 2015; Abud et al., 2018; Arruda et al., 2018; Severiano & Pinheiro, 2018)..

The problem of the grain harvest preserving and protecting it from harmful organisms during storage is very relevant in agriculture, since a large number of agricultural products are stored without providing the necessary conditions for this. An important aspect of obtaining high-quality products is to determine the degree of grain contamination before it is stored by direct visual observation or using instrumental methods that reveal the hidden forms of seeds infection by diseases and damage by pests (Dumitru et al., 2020).

It is obvious that the phytosanitary control of crops with the use of advanced technologies and modern plant protection products is a necessary condition for high grain yields obtaining. It is notable that the seed material' phytosanitary condition, which would prevent the infectious diseases emergence and development and contributed to the improvement of crops, needs for the most attention (Gagkaeva et al., 2009; Firsova et al., 2019).

Instrumental high-tech analysis methods comply with modern requirements for identification of the seed material quality. They take into account the features and defects of the internal structure on which the viability of seeds depends. The possibilities and advantages of such methods and their extended informativeness are described in detail in the work of Musaev et al., 2017. The method of microfocus radiography through the seeds internal structure visualizing allows us to identify such signs as: the presence of internal injury, the biological degree of the germ and endosperm plumpness, the presence of diseases infection, infestation and damage by pests. For vegetable crops and their selection without germination, it is possible to determine the separateness, singleness, self-fertility. Differences between varietal-population and hybrid seeds (experiments with radish) are also well detected using microfocus radiographs by the degree of plumpness of internal structures.

The analysis of digital images of agricultural crops' seeds is an important tool not only for the study of their heterogeneity, but also serves as the basis for the creation of automatic seed sorters (separators) that allow to obtain the seed material with improved sowing qualities compared to the initial ones (Sandeep et al., 2013). The analysis of a combine grain yield monitoring system is given in the work of Risius (2014). The developed system comprised a yield meter, GNSS receiver and a computer installed with customized software, which, when assembled on a local rice combine, mapped real-time rice yield along with grain moisture content (Sirikun et al., 2021).

The method of soft-beam microfocus radiography has been successfully used for many years both in Russia (Arkhipov et al., 2016; Potrakhov et al., 2019; Priyatkin et al., 2019) and abroad (Burg et al., 1995; Moreira et al., 1999; Gomes-Junior et al., 2012; Silva et al., 2012 and 2013; Franco et al., 2015). X-ray densitometry is a promising method for non-destructive evaluation of the seed's internal morphology of various crops and has great potential for development in the field of seed testing (Gomes-Junior et al., 2012). The Agrophysical Research Institute has developed highly informative methods for conducting radiography of seeds and plants, as well as modern technical means for their implementation (Musaev et al., 2020). Image analysis has been used recently both to the seed quality assess and to some aspects of seed physiology clarify. X-rays can be used successfully to identify physical abnormalities and their occurrence correlation with the physiological potential of seeds (Pereira da Silva et al., 2020). It can be used to detect various structural seeds defects, such as crack, enzymomycosis depletion, internal germination, hidden pest infestation, mechanical injuries and germ defects, empty grain, etc. (Haff & Slaughter, 2004; Panchal et al., 2014).

A promising direction for assessing the biological objects' general condition is the gas-discharge visualization (GDV) method, which allows recording and analyzing the gas-discharge glow induced in biological objects and their structures. This method gives the opportunity to control the quality of plant raw materials, in particular, fruits, seeds and grains (Priyatkin et al., 2006a).

The gas-discharge visualization technique is an important part of a complex methodology for the seed material quality assessing, as it combines together the seeds assessment using morphometric and automated radiographic methods (Arkhipov et al., 2014). It allows to obtain the data about the biological and economic suitability of seed material, to predict the field germination of seeds and their potential productivity (Priyatkin et al., 2006b).

A preliminary analysis of the characteristics of the seeds' gas-discharge glow is an essential addition to the main standardized methods for the seed quality assessment (Arkhipov et al., 2016). The study of the seed surface characteristics is carried out in the wavelength ranges from near ultraviolet to near infrared, including using several light sources with different wavelengths, which allows multispectral images obtaining (Olesen et al., 2015). In the last 10 years, data have emerged on the possibility of using the terahertz imaging method to determine the varietal purity of seeds (Lu et al., 2005), the quality of seed material (Ge et al., 2014), as well as the early prediction of laboratory seed germination (Jiang et al., 2016).

The data on the possibility of using the terahertz imaging method to determine the varietal purity of seeds (Lu et al., 2005), the quality of seed material (Ge et al., 2014), as well as the early prediction of laboratory seed germination (Jiang et al., 2016) have obtained for the last 10 years.

However, the system analysis studies of changes in wheat productivity and resistance to pathogens depending on the seeds structural and functional characteristics have not been conducted. Earlier, the effectiveness of wheat stimulating treatments with microbiological biopreparations, was evaluated using the above methods of introscopic analysis of wheat grain, and the quality of the newly harvested crop and changes in wheat diseases resistance were analyzed (Kolesnikov et al., 2019, 2020a, 2020b).

The aim of the work is to reveal the dependence of the soft wheat productivity elements and diseases resistance on the structural and functional characteristics of seeds.

The indicators of the grains' structural and functional activity, associated with the hidden heterogeneity of the seed material, for the first time in the Leningrad region conditions were analyzed, and the interrelations in the change of the productivity elements and wheat diseases resistance were revealed by more than 30 optical parameters, including gas-discharge glow, morpho- and densitometric analysis of radiographs. The practical value of the work lies in the development of tools for programming the yield and increasing the wheat diseases resistance through the selection of high-quality seed material when determining its latent heterogeneity by microfocus radiography and gas-discharge visualization.

MATERIALS AND METHODS

The field experimental study the influence of structural and functional characteristics of soft wheat seed material on the wheat productivity and diseases resistance was carried out at the scientific and production base 'Pushkin and Pavlovsk Laboratories of VIR' of the Vavilov All-Russian Institute of Plant Genetic Resources (VIR). 10 cultivars of spring wheat (*Triticum aestivum* L.) from the collection of the wheat genetic resources Department of VIR were used as plant experimental material: Omskaya 18, k-58220; Kolkhoznitsa, k-30177; Saratovskaya 29, k-40599; Leningradka, k-47882; Moskovskaya 35, k-48762; HD 2329, k-58775; Leningradskaya 97, k-62935; Tulunskaya 12, k-64361; Rostan', k-64391; Ester, k-64544.

All grains of each of the 10 wheat cultivars had a 'parametric passport' (for more than 30 optical parameters, including gas - discharge glow, morpho- and densitometric analysis of X-rays) when assessing the impact of seed quality on wheat productivity and disease resistance. The sample size for each cultivar was 105 grains (Fig. 1).

Figure 1. Soft wheat grains used as seed material with a 'parametric passport'.

To take into account the individual characteristics of the seeds, a separation mesh was used. The area of the accounting plot for one sample was 1.3 m^2. Samples for plots were sown manually by an rows seeding method with row spacing of 15 cm and a distance in a row of 1–2 cm. Seed depth: 5–6 cm (Fig. 2).

Gas-discharge and X-ray characteristics of wheat seeds used as seed material were determined on the experimental equipment of the Plant Biophysics sector of the AFI Federal State Budgetary Institution.

Hardware and software of the method of gas-discharge visualization (electrophotography) of wheat seeds is presented by the serial device 'GRV-Camera' analysis of digital gas-discharge images 'GRV Scientific Laboratory'.

Figure 2. The beginning of the field experience for the study of the wheat yield and disease resistance dependence on the structural and functional characteristics of wheat seeds.

The method of gas-discharge visualization (electrophotography) of wheat seeds was carried out by the use of serial device ‘GRV-Camera’ in complete with software for the analysis of digital gas-discharge images ‘GRV Scientific Laboratory’. Developer and manufacturer of hardware and software complex - LLC ‘Biotechprogress’. This method allows to record and quantify the characteristics of the corona discharge that occurs when the seed is placed in a high-intensity electromagnetic field (Fig. 3).

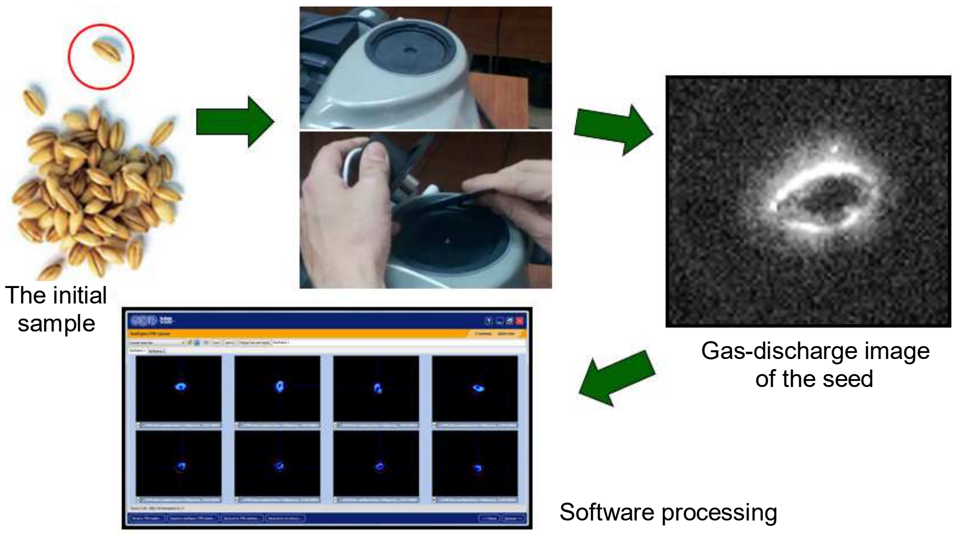

Figure 3. The algorithm for wheat seeds analysis by gas-discharge visualization.

When using the gas-discharge visualization method, wheat seeds were characterized by the following indicators: glow area (cm^2), total glow intensity (relative units), shape coefficient (relative units), average contour radius (pixels), normalized standard deviation of the contour radius (pixels), contour length (pixels), entropy calculated from the contour (relative units), fractality calculated from the contour (relative units), X-ray images were obtained on a serial mobile X-ray diagnostic unit PRDU-02 (CJSC ‘ELTECH-Med’). The analysis of digital X-ray images of wheat seeds was performed by the use the tablet scanner EPSON Perfection V200 Photo and software 'Agrus-Bio' produced by LLC 'ArgusSoft' (Fig. 4).

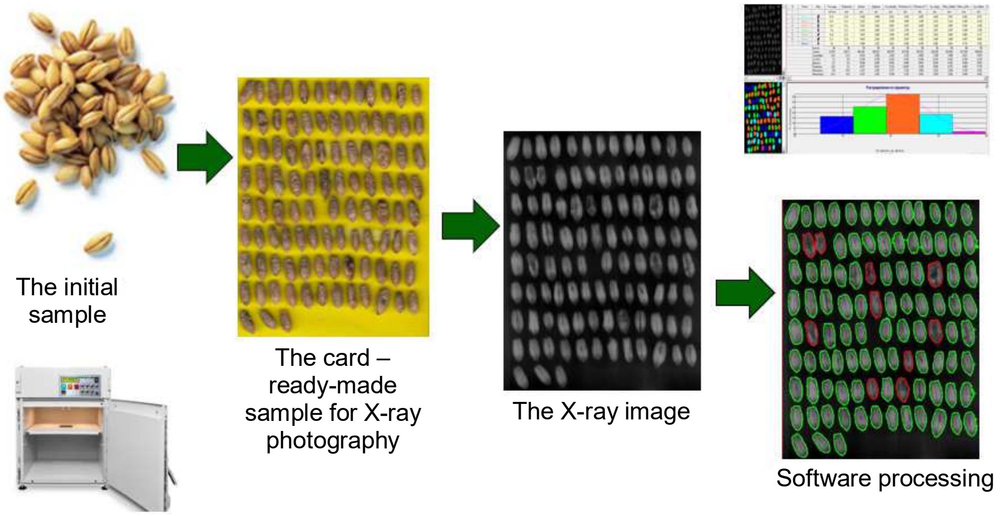

Figure 4. The algorithm for wheat seeds analysis by microfocus radiography.

When using the microfocus X-ray method, wheat seeds were characterized by the following indicators: the area of the X-ray projection of the seed (cm^2), the perimeter of the X-ray projection of the caryopsis (cm), the length of the X-ray projection of the seed (cm), the width of the X-ray projection of the seed (cm), the roundness of the X-ray projection of the seed (relative units), the elongation of the X-ray projection of the seed (relative units), the deviation of the brightness of the X-ray projection of the seed (units of brightness), the optical density of the X-ray projection of the seed (relative units) and the integral optical density of the X-ray projection of the seed (relative units).

Wheat productivity was studied in three times replication in the phases of germ shoot development, earing-flowering and maturation according to a set of indicators. In the germ shoot development phase, wheat cultivars were evaluated according to the generally accepted indicator - field germination (%). In the ear–flowering phase, the complex of plant indicators: the productive and total bushiness (pcs.), the plant phase (score, on the Zadox scale (Eucarpy), the flag and pre-flag leaf area (cm^2), the plant height (cm), the spike length (cm), the spikelets number per spike (pcs.), the spike weight (g) was studied. In addition, the number and length of roots (main germ root, germ and coleoptile roots) extending from the epicotyle were determined. The number and length of wheat nodal roots were taken into account. The roots' and plants' vegetative part weight was calculated (Kolesnikov, Kremenevskaya et al., 2020; Kolesnikov, Novikova et al., 2020).

In the maturation phase (phase of full ripeness) the wheat yields structure was studied by the indicators: the number of spikelets per spike, pcs.; the spike length, cm; the spike weight; the grains number per spike, pcs.; the grains weight, the 1,000 grains weight. The potential (biological) yield of a single wheat plant was calculated by the indicators: the productive bushiness and grain weight per one plant spike (g plant). The wheat cultivars’ potential yield (Y_p) in relation to the sowing area (t ha^{-1}) was calculated by the productive bushiness, the grains weight per spike and the number of plants sown per 1 m^2. The assessment of the plant damage degree by diseases was carried out in the main phases of wheat ontogenesis (Kolesnikov, Kremenevskaya et al., 2020; Kolesnikov, Novikova et al., 2020).

The size of pathogens’ infectious structures formed on leaves during pathogenesis (spots, pustules, etc.) was calculated using ocular and objective micrometers. The pustule area values for rust fungi and the spots area for powdery mildew were determined by the ellipse area formula (Fig. 5).

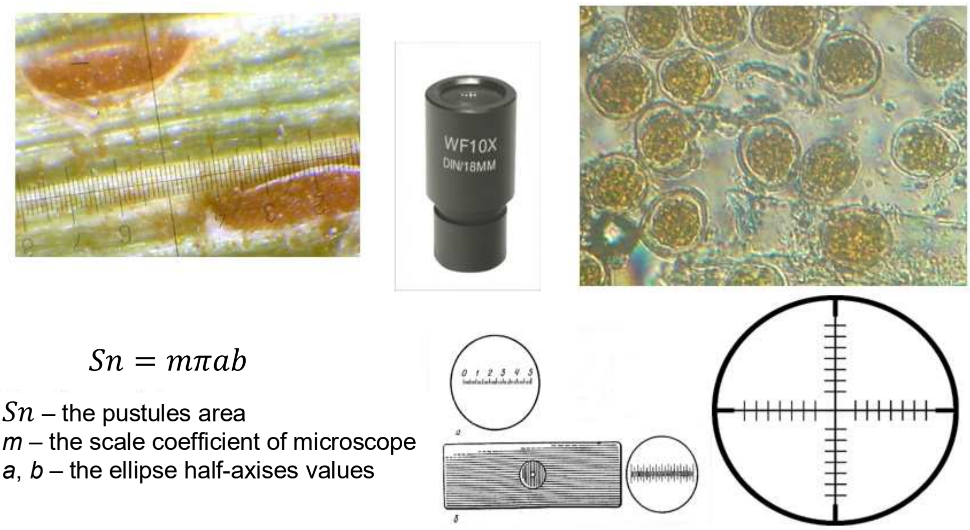

Figure 5. The wheat brown rust uredopustules’ size calculation.

Statistical analysis of the experimental results was carried out in the PC programs SPSS 26.0, Statistica 10.0, Excel 2019. The calculations were performed by the use of parametric statistical methods (based on the *mean M* and their *standard errors* ± *SEM*, 95% confidence intervals, and Student's *t-test*). The relationships between the indicators were analyzed using *Spearman's rank correlation*. When identifying the most important factors that affect the dependent variable and constructing numerical dependencies, the method of nonlinear regression analysis was used.

RESULTS AND DISCUSSION

The possibility of the wheat seeds quality controlling using non - destructive testing methods: gas-discharge visualization and microfocus radiography for programming wheat yield and predicting changes in the intensity of wheat damage by diseases was studied as a result of the conducted research.

Identification of soft wheat non-viable and healthy seeds by gas-discharge visualization

The area of gas-discharge characteristics of soft wheat seeds was compared with the following signs of field germination: the seeds did not shoots (non - viable seeds - NVS); the seeds have shoots (viable (healthy, fulfilled) seeds -VS); the seeds have shoots, but the plants died (conditionally viable seeds - CVS). A slight decrease in the area of the gas-discharge image (GDI) of non-viable seeds that did not germinate, compared with viable seeds that sprouted, was found in 40% of the studied wheat cultivars (Saratovskaya 29, k-40599 - by 0.9%; Leningradskaya 97, k-62935 - by 8.0%; Tulunskaya 12, k-64361 - by 0.8%; Ester, k-64544 - by 0.1%). The greatest differences in the seeds GDI area change in the direction of decrease were noted in the CVS compared to the VS. This tendency was found in 80% of cultivars. The CVS was characterized by the GDI smaller area compared to VS (significantly by 12.0%, $t = 2.4$ - Saratovskaya 29, k-40599; by 14.0%, $t = 2.6$ - Leningradka, k-47882; by 6.7%, $t = 9.0$ - Tulunskaya 12, k-64361; by 19.0%, $t = 3.1$ - Ester, k-64544, and by 1.01% - Moskovskaya 35, k-48762; by 0.9% - HD 2329, k-58775; by 0.6% - Leningradskaya 97, k-62935; by 1.2% - Rostan', k-64391).

Compared with viable seeds, non-viable seeds were characterized mainly by large values of the brightness index of the gas-discharge image. This pattern was found in 70% of cultivars. The decrease in the average intensity of the gas discharge image brightness was revealed on the UVS of 30% cultivars (Moskovskaya 35, k-48762 - 2.1%; Leningradskaya 97, k-62935 - 1.2%; Tulunskaya 12, k-64361 - 5.0%) and on the CVS of 70% cultivars (significantly by 3.6%; $t = 2.9$ - Leningradskaya 97, k-62935; 7.8%; $t = 12.0$ - Tulunskaya 12, k-64361; 15.1%; $t = 3.0$ - Ester, k-64544, and also by 1.2% - Saratovskaya 29, k-40599; by 3.4% - Leningradka, k-47882; by 0.9% - Moskovskaya 35, k-48762). It should be noted that in the work of Arkhipov et al (2016), a negative correlation between this indicator and the parameters: seedling length (cm), the wheat flag leaf area, was found. The revealed regularity makes it possible to use the brightness indicator of the gas-discharge visualization for express selection of seeds with the best sowing qualities (Cater & Batic, 1998; Zanco, 2016).

The GDI shape coefficient may reflect the 'thinness' of grains caused by enzymomycosis depletion (Arkhipov et al., 2016). The shape coefficient is the ratio of the GRV image glow external contour' perimeter in a square to its area. In 40% of cultivars a decrease in the shape coefficient values on the CVS, compared to the VS, was recorded (significantly by 2.8%; $t = 2.8$ - Leningradka, k-47882; by 8.9%; $t = 2.8$ - Omskaya 18, k-58220; by 2.1%; $t = 3.0$ - Ester, k-64544, and also by 1.1% - Saratovskaya 29, k-40599). The shape coefficient values on the CVS decreased in 40% of cultivars compared to VS (by 10.3% - Kolkhoznitsa, k-30177; by 13.1% - Saratovskaya 29, k-40599; by 9.5% - Moskovskaya 35, k-48762; by 3.1% - HD 2329, k-58775. In the work of Arkhipov et al (2016), the positive correlation with the parameter 'GDI shape' and 'the 1,000 seeds weight' was found.

In comparison with VS, a decrease in three - dimensional fractality along the isoline of the gas-discharge image was found on 40% of the NVS cultivars (significantly by 2.8%; $t = 2.9$ - Leningradka, k-47882; by 8.9%; $t = 7.7$ - Omskaya 18, k-58220; by 2.1%; $t = 3.1$ - Ester, k-64544, and also by 1.1% - Saratovskaya 29, k-40599). A similar tendency was found in 40% of cultivars with the CVS (by 10.3% - Kolkhoznitsa, k-30177; by 13.1% - Saratovskaya 29, k-40599; by 9.5% - Moskovskaya 35, k-48762;

by 3.1% - HD 2329, k-58775). Supposedly, the fractal parameter depends on the seeds size characteristics. In the work of Arkhipov et al (2016) a positive correlation between this indicator and the 1,000 seeds weight was found. No such studies have been conducted in the world.

The standard deviation (SD) of GDI fractality was reduced in NVS (70% of cultivars) and CVS (60% of cultivars) compared to healthy seeds.

Reliable reduction in the gas discharge image contour irregularity of the NVS compared to VS was detected in 50% of cultivars (by 33%; t = 13.8 - Leningradka k-47882; 29.7%; t = 18.3 - Moskovskaya 35, k-48762; 19.9%; t = 12.5 - Omskaya 18, k-58220; 3.2%; t = 2.8 Tulunskaya 12, k-64361; 3.1%; t = 2.5 - Ester, k-64544) and 30% cultivars with CVS (by 84,5%; t = 5.0 - HD 2329, k-58775; 34.4%; t = 2.5 - Leningradskaya 97, k-62935; 19.9%; t = 3.2 - Tulunskaya 12, k-64361.

The isoline average radius displays the 'width' of the glow around the object, the normalized SD of the isoline radius makes it possible to estimate the unevenness of the glow width along the contour (Arkhipov et al., 2016).

In NVS of 40% of cultivars, a decrease in the isoline average radius in comparison with VS was observed (significantly by 6.0%; t = 2.3 - Moskovskaya 35, k-48762; by 4.7%; t = 3.6 - HD 2329, k-58775; by 12.9%; t = 5.1 - Leningradskaya 97, k-62935; by 4.3%; t = 2.5 - Ester, k-64544). This tendency was also revealed in the remainder of 60% of cultivars when analyzing the isoline average radius of the CVS compared to the VS (significantly by 24.0%; t = 7.5-Leningradka, k-47882; by 13.4%; t = 2.3-HD 2329, k-58775; by 9.2%; t = 2.3-Leningradskaya 97, k-62935; by 28.4%; t = 19.1 - Tulunskaya 12, k-64361; by 10.0%; t = 8.3 - Rostan', k-64391, and also by 6.4% - Ester, k-64544).

The increase in values of normalized SD GRI isoline radius on the CNV was detected in 60% of cultivars (significantly by 10.2%; t = 2.8 to Omskaya 18 k-58220; 11.3%; t = 2.5 - Leningradka, k-47882 and 2.8% - Kolkhoznitsa, k-30177; 2.2% - Saratovskaya 29, k-40599; 5.4% - Tulunskaya 12, k-64361; 4.4% - Rostan', k-64391) and on the CVS in 30% cultivars, compared to VS (by 11.3% - Kolkhoznitsa, k-30177; 8.9% - Saratovskaya 29, k-40599; 12.4% Moskovskaya 35, k-48762).

The entropy values along an isoline were reduced on the NVS and the CVS, compared to healthy seeds. This regularity was revealed in 60% of the cultivars on the NVS (significantly by 3.5%; t = 3.8 Kolkhoznitsa, k-30177; 0.8%; t = 4.1 - Saratovskaya 29, k-40599; 1.1%; t = 3.1 - Omskaya 18 k-58220; 0.7%; t = 6.8 - Leningradskaya 97, k-62935; 1.1%; t = 2.4 - Tulunskaya 12, k-64361) and in 30% of the cultivars on the CVS (2.5% Moskovskaya 35, k-48762; 0.9% Leningradskaya 97, k-62935; 4.9% - Ester, k-64544). In the work of Arkhipov et al. (2016) the positive correlation between this indicator and the seed germination energy was revealed.

The isoline length is an important indicator of seed quality. In our experience, the greatest decrease in the indicator was registered in the group of CVS, compared with the VS. This pattern was found in 60% of cultivars (significantly by 11.6%; t = 2.8 - Leningradka, k-47882; by 9.7%; t = 2.3 - HD 2329, k-58775; by 5.2%; t = 7.6 - Tulunskaya 12, k-64361; by 3.6%; t = 4.7 - Rostan', k-64391; by 5.7%; t = 2.7 - Ester, k-64544). Only 30% of cultivars were characterized by reduced values of the indicator on NVS. It should be noted that in the work of Arkhipov. et al (2016) a positive correlation between the isoline length and the 1,000 seeds weight was noted.

Previously, the GDI characteristics, obtained on wheat seeds that had no visible signs of damage - 'seemingly healthy', having a weak and strong degree of infection caused by the spike fusariose agent *Fusarium* spp., was studied by Priyatkin and co-authors (2006). It was revealed that «seemingly healthy» seeds were characterized by the maximum values of the GDI parameters: brightness distribution, shape coefficient and three-dimensional fractality compared to infected seeds. GDI of 'seemingly healthy' seeds were distinguished by a more rugged contour and a variety of brightness spectrum than infected grains. When studying the seeds of common spruce (*Picea abies* L.) by gas-discharge imaging, it was noted that the NVS did not shown a gas-discharge glow, in contrast to the seeds that subsequently sprouted, which can be explained by the fact that the gas-discharge imaging method is sensitive to humidity and electrical conduction of the object. In NVS, humidity and electrical conduction are lower due to the absence of the germ and endosperm, so the initialization of gas-discharge glow under the specified modes of the GRV-Camera device did not occur (Arkhipov et al., 2013).

Identification of non-viable and viable soft wheat seeds by microfocus soft-beam radiography

One of the indicators, characterizing the 'endosperm fullness', is of the seed projection area. The most decrease in the grain projection area on the CVS compared to the VS was recorded. This regularity was found in 50% of cultivars (significantly by 5.4%; t = 2.8 - Leningradka, k-47882; by 8.3%; t = 2.4 - Moskovskaya 35, k-48762; by 12.3%; t = 11.4 - Tulunskaya 12, k - 64361, by 4.2% - Saratovskaya 29, k-40599, by 2.2% - Leningradskaya 97, k-62935). A decrease in the projection area of NVS compared to VS was recorded in 40% of cultivars (significantly by 3.3%; t = 2.4 - Saratovskaya 29, k-40599; by 2.1%; t = 2,3 - Omskaya 18, k-58220; by 5,6%; t = 2.2 - Leningradskaya 97, k-62935; by 2.6% - Rostan', k-64391).

The most expressed decrease in the seed projection perimeter on the CVS compared to the VS was registered. This pattern was found in 50% of cultivars (significantly by 7.8%; t = 12.3 - Tulunskaya 12, k-64361; by 3.1%; t = 2.1 - Leningradskaya 97, k-62935; by 0.8% - Saratovskaya 29, k-40599; by 0.1% - Leningradka, k-47882; by 1.6% - Moskovskaya 35, k-48762). A decrease in the NVS projection perimeter compared to the VS was registered only in 30% of cultivars (significantly by 0.7%; t = 2.1 - Omskaya 18, k-58220; by 2.7%; t = 3.2 - Leningradskaya 97, k-62935, and also by 0.9% - Saratovskaya 29, k-40599).

The most reduction in the seed projection length was recorded in the CVS compared to the VS. This pattern was found in 40% of cultivars (significantly by 9.5%, t = 2.5 - Leningradka, k-47882; by 12.5%, t = 2.5 - Moskovskaya 35, k-48762; by 6.2%, t = 9.0 - Tulunskaya 12, k-64361, and also by 1.8% - Leningradskaya 97, k-62935). A decrease in the NVS projection length in comparison with healthy seeds was also recorded on 40% of cultivars (significantly by 1.0%, t = 4.3 - Saratovskaya 29, k-40599; by 1.0%, t = 2.3 - Leningradka, k-47882; by 7.7%, t = 14.3 - Omskaya 18, k-58220; by 8.4%, t = 22.3 - Rostan', k-64391).

The most decrease in the seed projection width was registered in the CVS compared to the VS. This was found on 50% of cultivars (significantly by 7.2%, t = 9.4 - Moskovskaya 35, k-48762; by 2.7%, t = 5.1 - Tulunskaya 12, k-64361; by 5.0% - Saratovskaya 29, k-40599; by 1.5% - Leningradka, k-47882; by 2.4% - HD 2329, k-58775, by 0.2% - Leningradskaya 97, k-62935). A decrease in the NVS projection width compared to VS was also recorded on 50% of cultivars (significantly by 2.5%, t = 18.0 - Saratovskaya 29, k-40599; by 0.5%, t = 2.6 - Omskaya 18, k-58220; by 1.9%, t = 16.3 - HD 2329, k-58775; by 2.9%, t = 12.2 - Leningradskaya 97, k-62935; by 2.9%, t = 6.2 -Rostan', k-64391).

The most decrease in the seed projection' average chord was registered in the CVS compared to the VS. This pattern was found on 60% of cultivars (significantly by 10.2%, t = 9.3-Saratovskaya 29, k-40599; by 6.4%, t = 2.4 - Leningradka, k-47882; by 3.4%, t = 2.2 - Leningradskaya 97, k-62935; by 8.0%, t = 15.5 - Tulunskaya 12, k-64361; by 3.11%, t = 6.5 - Rostan', k-64391). A decrease in the NVS projection' average chord, compared with healthy seeds, was also recorded on 30% of cultivars (significantly by 3.8%, t = 26.2 - Kolkhoznitsa, k-30177; by 3.4%, t = 9.5 - Leningradskaya 97, k-62935; 6.8%, t = 44.1 kHz - Saratovskaya 29, k-40599).

70% of the NVS wheat cultivars in was characterized by greater elongation of the seed projection compared to VS (significantly by 1.8%, t = 24.9 - Saratovskaya 29, k-40599; 2.1%, t = 5.3 - Leningradka, k-47882; 2.4%, t = 31.6 - Moskovskaya 35, k-48762; 1.6%, t = 16.9 - HD 2329, k-58775; 2.8%, t = 8.9 - Tulunskaya 12, k-64361; 0.5%, t = 2.2 - Rostan', k-64391; 0.8% t = 5.2 - Ester, k-64544). A decrease in the of the CVS projection elongation, in comparison with the VS, was recorded in 50% of the cultivars.

The most decrease in the seed projection size was recorded on NVS. This pattern was found in 50% of cultivars (significantly by 1.5%, t = 9.8 - Saratovskaya 29, k-40599; by 0.3%, t = 22.7 - Omskaya 18, k-58220; by 2.1%, t = 2.8 - HD 2329, k-58775; by 0.1%, t = 5.6 - Leningradskaya 97, k-62935; by 5.9%, t = 12.8 - Rostan', k-64391). A decrease in the CVS size was shown by 30% of cultivars.

Smaller values of the NVS projection' circle factor compared to VS were detected in 70% of wheat cultivars (significantly by 1.3%, t = 9.8 - Kolkhoznitsa, k-30177; 1.5%, t = 8.8 - Saratovskaya 29, k-40599; 0.3%, t = 9.8 - Leningradka, k-47882; 0.3%, t = 9.1 - HD 2329, k-58775; 0.2%, t = 9.8 - Leningradskaya 97, k-62935; 0.1% t = 12.8 - Tulunskaya 12, k-64361; 0.3%, t = 13.8 - Rostan', k-64391). In the case of CVS, the tendency of circle factor decrease was observed only in 40% of cultivars.

The most increase in the values of the seed projection ellipse factor was registered on the CVS compared to the VS. This tendency was found in 60% of cultivars. In the same time, the NVS were characterized by lower values of the indicator in 50% of cultivars.

A decrease in the values of the seed projection roundness on the NVS and CVS, compared with the VS, was revealed. This trend was identified in 60% (reliably by 2.7%; t = 85.9 - Kolkhoznitsa, k-30177; by 1.9%; t = 104,8 - Saratovskaya 29, k-40599; 5.9%; t = 40.4 - Moskovskaya 35, k-48762; 0.6%; t = 3.9 - Leningradskaya 97, k-62935; 0.5%; t = 3.4 - Tulunskaya 12, k-64361; 3.2%; t = 103.2 - Ester, k-64544) and 70% of cultivars (significantly by 5.2%; t = 3.3 - Leningradskaya 97, k-62935; 3.3%; t = 5.7 - Tulunskaya 12, k-64361; 22.1%; t = 42.1 - Rostan', k-64391, by 5.0%; t = 5.7 - Kolkhoznitsa, k-30177; by 6.2% - Saratovskaya 29, k-40599; by 7.0% - Leningradka, k-47882), respectively.

A lower average brightness of the NVS projection was marked in 40% of wheat cultivars compared to the VS (significantly by 0.8%, t = 2.2 - Saratovskaya 29, k-40599; 1.7%, t = 3.7 - Omskaya 18 k-58220; 3.7%, t = 2.6 - Rostan', k-64391 and reliably by 6.4%, t = 2.6 - Moskovskaya 35, k-48762; 3.7%, t = 11.3 - Rostan', k-64391; 7.0%, t = 0.9 - Leningradka k-47882; 1.5%, t = 2.9 - Saratovskaya 29, k-40599).

The NVS and CVS were distinguished by a greater SD of the seed projection' average brightness compared to VS. This dependence revealed in 40% of the cultivars (significantly by 2.7%, t = 4.0 - Moskovskaya 35, k-48762; 3.6%, t = 5.9 - Leningradskaya 97, k-62935; 3.3%, t = 7.5 - Tulunskaya 12, k-64361; 5.6%, t = 14.6 - Rostan', k-64391 and 13.6%, t = 2.4 - Leningradka, k-47882; 6.9%, t = 2.6 - Leningradskaya 97, k-62935; 4.8%, t = 2.3 - Saratovskaya 29, k-40599).

The decrease in the minimum average brightness of the NVS projection compared to the VS was revealed in 60% of cultivars (significantly by 0.5%, t = 6.0 to Saratovskaya 29, k-40599; 0.2%, t = 2.3 - Leningradka k-47882; 2.4%, t = 5.5 - Omskaya 18 k-58220; 1.9%, t = 2.7 - HD 2329, k-58775; 9.8%, t = 2.3 - Rostan', k-64391; 0.6%, t = 10.9 - Ester, k-64544, and by 0.7% Moskovskaya 35, k-48762). The tendency of the minimum average brightness decreasing in 30% of cultivars on the CVS in comparison with VS was identified.

In 50% and 60% of wheat cultivars with NVS and CVS, seed projections were characterized by a lower maximum brightness compared to VS.

A decrease in the brightness interval in the NVS and CVS (compared to the VS) was registered. This trend was identified in 50% (significantly by 0.6%, t = 14.5 - Leningradskaya 97, k-62935, by 8.6% - Saratovskaya 29, k-40599; 2.7% Moskovskaya 35, k-48762; 0.6% - Tulunskaya 12, k-64361; 0.3% - Ester, k-64544) and in 70% of cultivars (significantly by 20.5%, t = 2.6 - Moskovskaya 35, k-48762; 22.3%, t = 4.6 - Leningradskaya 97, k-62935; 10.9%, t = 7.8 - Tulunskaya 12, k-64361; 2.4%, t = 2.6 - Rostan', k-64391, by 9.5% - Saratovskaya 29, k-40599; 10.5% - Leningradka k-47882; by 0.9% - Ester, k-64544).

An increase in the optical density of the NVS and CVS projection in comparison with VS was determined. This tendency was revealed in 50% (0.4% - Saratovskaya 29, k-40599; 0.2% Moskovskaya 35, k-48762; 0.7% - in Omskaya 18 k-58220; 0.1% HD 2329, k-58775; 1.6% - Rostan', k-64391) and 40% of the cultivars (significantly by 2.4%, t = 2.3 - Moskovskaya 35, k-48762; 1.5%, t = 12.0 - Rostan', k-64391, and 0.7% - Saratovskaya 29, k-40599; 2.9% - Leningradka k-47882).

A growth of the integral optical density values on the NVS compared to the VS in 60% of cultivars was marked (significantly by 8.0%, t = 2.5 - Moskovskaya 35, k-48762; 5.7%, t = 2.8 - Tulunskaya 12, k-64361, by 0.6% - Kolkhoznitsa, k-30177; 4.0% - Leningradka k-47882; 1.8% - HD 2329, k-58775; 2.1% - Ester, k-64544). In 40% of the cultivars with CVS, a tendency to increase the integral optical density in comparison with VS was revealed.

The identification of wheat productivity and intensity of diseases development dependences on gas-discharge characteristics of seed material

The data about the yield structure and diseases development intensity on wheat cultivars of different origin are presented in the Table 1. For the period of phytosanitary monitoring of wheat as diseases causative agents were identified: brown rust (*Puccinia recondita* Rob. ex Desm. f. sp. *tritici* Eriks.), wheat leaf blotch (*Stagonospora nodorum* Castell.et Germano) and powdery mildew (*Blumeria graminis* Speer.). Samples from the European part of the Russian Federation had better indicators of yield structure than samples from the Asian part of the Russian Federation. The maximum grain weight per plant was marked on the sample Rostan', k-64391 from Eastern Europe (Belarus) - 2.36 ± 0.15 g plant.

Table 1. The yield structure and the intensity of plant pathogens development on cultivars with different origin

Origin	Spike length (cm)	Number of spikelets (pcs.)	Number of grains per spike (pcs.)	Grain weight per plant (g)	Development of brown rust (%)	Development of wheat leaf blotch (%)	Development of powdery mildew (%)
Russia, the European part	7.60* ± 0.06 (7.49–7.71)	13.61 ± 0.08 (13.44–13.78)	19.80 ± 0.26 (19.31–20.29)	1.73 ± 0.08 (1.59–1.87)	28.40 ± 2.13 (24.93–31.86)	80.89 ± 1.46 (78.21–83.55)	1.34 ± 0.13 (0.97–1.71)
Russia, the Asian part	6.53 ± 0.06 (6.41–6.66)**	12.73 ± 0.10 (12.54–12.91)	18.09 ± 0.26 (17.53–18.66)	1.69 ± 0.08 (1.52–1.87)	17.76 ± 1.77 (13.31–22.20)	86.48 ± 1.69 (83.22–89.73)	2.63 ± 0.29 (2.17–3.08)
Eastern Europe (Belarus)	6.95 ± 0.08 (6.75–7.15)	15.27 ± 0.14 (14.98–15.57)	24.38 ± 0.51 (23.49–25.27)	2.36 ± 0.15 (2.08–2.64)	14.84 ± 2.29 (7.48–22.19)	86.14 ± 1.89 (80.79–91.48)	0.02 ± 0.02 (0.00–0.77)
South Asia (India)	6.48 ± 0.11 (6.18–6.77)	11.39 ± 0.20 (10.95–11.83)	16.44 ± 0.62 (15.12–17.74)	1.66 ± 0.14 (1.22–2.11)	0.35 ± 0.16 (0.10–12.38)	89.56 ± 3.13 (80.96–98.16)	5.80 ± 1.54 (4.50–7.09)

* – Mean and standard error of mean; ** – 95%-confidence interval.

The cultivars from the European part of the Russian Federation in comparison with the samples from the Asian part had the best indicators of yield structure and the highest values of the GDI area and the of the seeds GDI glow average intensity (Fig. 6).

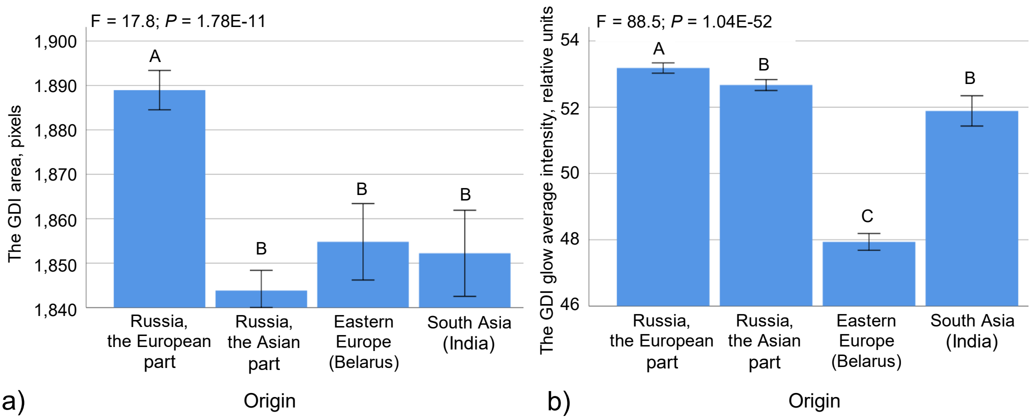

Figure 6. The area (a) and the average glow intensity of GDI (b) of soft wheat seeds with different origin. The graphs show the average values of the indicators and standard error of mean. The same letters mark the values of the indicator that are not significantly different according to the Scheffe criterion. F – Fisher criterion according to the single-factor analysis of variance.

The highest values of the area and the glow average intensity of the seeds GDI were found in wheat cultivars from the 2nd climatic zone of the Russian Federation, adapted to warmer growing conditions, compared with samples from the 3rd climatic zone (Table 2). Natural and climatic factors can have a significant impact on the intensity of the wheat diseases development (Kolesnikov et al., 2009), to modify the plant resistance manifestation, in particular, associated with both the expression of plant resistance genes and pathogens virulence genes (Naseri & Sasani, 2020a; Naseri & Sabeti, 2020b). Naturally changing environmental conditions can develop a genetic adaptation to these conditions in plants. Our studies have shown that the least development of brown rust was recorded on cultivars from the third climate zone of the Russian Federation, which can be explained by the low virulence and aggressiveness of local phytopathogen populations in relation to wheat cultivars from another climatic zone.

Table 2. The yield structure and the intensity of plant pathogens development on cultivars from different climatic zones

Climatic zones	Spike length (cm)	Number of spikelets (pcs.)	Number of grains per spike (pcs.)	Grain weight per plant (g)	Development of brown rust (%)	Development of wheat leaf blotch (%)	Development of powdery mildew (%)
The second climate zone of the Russian Federation (Leningrad, Moscow, Saratov region).	7.60 ± 0.06* (7.49–7.71)**	13.61 ± 0.08 (13.44–13.78)	19.80 ± 0.26 (19.31–20.30)	1.73 ± 0.08 (1.58–1.87)	28.40 ± 2.13 (24.93–31.86)	80.89 ± 1.46 (78.21–83.56)	1.34 ± 0.13 (0.97–1.71)
The third climate zone of the Russian Federation (Irkutsk, Omsk region, Krasnoyarsk region)	6.53 ± 0.06 (6.41–6.61)	12.73 ± 0.10 (12.54–12.91)	18.09 ± 0.26 (17.53–18.66)	1.69 ± 0.08 (1.52–1.86)	17.76 ± 1.77 (13.31–22.20)	86.48 ± 1.69 (83.22–89.73)	2.63 ± 0.29 (2.17–3.08)

* – Mean and standard error of mean; ** – 95%-confidence interval.

The tendency of increase of most indicators of wheat productivity with a reduction in the GDI area, SD of isoline radius of seeds GDI, average chord, and elongation with the increase of entropy along isoline GDI, the isoline GDI length was revealed by the correlation analysis method. In particular, the grains number per spike of the cultivar HD 2329, k-58775 increased with a growth the GDI brightness average intensity ($r = 0.6$; $P = 0.01$), the entropy along isoline ($r = 0.4$; $P = 0.03$), the isoline average radius ($r = 0.4$; $P = 0.01$) and decrease in shape coefficient ($r = 0.6$; $P = 0.01$), normalized SD of the isoline radius ($r = -0.6$; $P = 0.004$). The spikelets number per spike of the HD 2329, k-58775 cultivar increased with a growth in the GDI brightness average intensity ($r = 0.4$; $P = 0.02$) and a decrease in the isoline radius SD ($r = -0.5$; $P = 0.008$), the shape coefficient ($r = -0.6$; $P = 0.001$). A positive dependence was found between the GDI area of wheat grain used as a seed material and the flag leaf area of HD 2329, k-58775 wheat cultivar. This pattern is typical for 42% of the seed material and reflects the associated growth of indicators.

The data on the equity distribution of positive and negative correlation coefficients that characterize the relationships between wheat productivity indicators, diseases development intensity and gas-discharge characteristics of wheat seeds were obtained during the research.

In particular, the increasing tendency in 45.4% of productivity indicators with a decrease in the seeds GDI area, was revealed. Wheat affect by brown rust have increased with the growth of the GDI area. In the same time, for wheat leaf blotch and powdery mildew the opposite trend was revealed. A positive correlation between 36.3% of productivity indicators and the average intensity of seed glow dominated. Inverse relationship was typical for 18.1% of the indicators. The wheat affect by brown rust have increased with the increase of the optical index, while affect by wheat leaf blotch and powdery mildew declined.

The increase in the seeds GDI shape coefficient values led to a growth of 36.3% of the indicators: plant height, plant vegetation phase, productive tillering, total tillering and a decrease of 45.5% of the indicators - spikelets number per spike, spike length, spike weight, grains number per spike and biological yield. The development intensity of the wheat leaf blotch and the brown rust pustules number have decreased with the indicator increasing, while powdery mildew –increased.

An increase in the entropy values along the seeds GDI isoline caused an increase in the values of 63.6% of productivity indicators and a decrease in the intensity of brown rust development, but led to an increase in plant damage by wheat leaf blotch. A decrease in the values of fractality along the seeds GDI isoline caused an increase of 63.6% of productivity indicators and an increase in plant damage by powdery mildew and wheat leaf blotch, but a decrease in damage by brown rust.

There was a tendency of increase of 36.4% of wheat productivity indicators with a decrease in the values of SD of fractality along the seeds GDI isoline. The development intensity of powdery mildew and wheat leaf blotch was negatively correlated with the values of this indicator, and brown rust was positively correlated.

A positive correlation was found between the brown rust development and the optical index. The opposite trend was revealed for the powdery mildew development on wheat.

The predominance of the growth tendency of 54.5% of productivity indicators with a decrease in the normalized SD of seeds GDI isoline radius was noted. A similar positive correlation for 36.4% of wheat productivity indicators was revealed. The wheat damage by brown rust decreased, while powdery mildew affect increased with the optical index growth.

There was a tendency of the predominance of growth of 36.4% of productivity indicators with an increase in the size of the GDI contour irregularity. The wheat damage by powdery mildew and leaf blotch decreased with the optical index increase, while brown rust affection increased.

An increase in the length of the seeds GDI isoline accompanied by a decrease in the values of 81.8% of productivity indicators, an increase in the brown rust development and a decrease in leaf blotch and powdery mildew.

Identification of the productivity and wheat diseases intensity dependence on the X-ray characteristics of seed material

The plants yield of the Saratovskaya 29, k-40599 cultivar increased with the growth in the seed projection width ($r = 0.3$; $P = 0.02$), the brightness deviation ($r = 0.4$; $P = 0.01$) and the integral brightness ($r = 0.5$; $P = 0.01$). On the Ester, k-64544 cultivar, an increase in plant yield with a decrease in the maximum and interval seeds brightness was noted ($r = -0.5$; $P = 0.01$ and $r = -0.4$; $P = 0.01$). The spike weight grew with an increasing of the seed projection width (Saratovskaya 29, k-40599 - $r = 0.5$; $P = 0.003$), of the values of average brightness deviations (Saratovskaya 29, k-40599 $r = 0.4$; $P = 0.01$; Tulunskaya 12, k-64361 - $r = 0.3$; $P = 0.04$).

The number of seedlings leaves of the Ester cultivar, k-64544 increased with a growth of the average chord ($r = 0.4$; $P = 0.03$) and a decrease of the seed projection optical density ($r = 0.5$; $P = 0.001$). An increase in the values of the circle factor of seeds projection of the Omskaya 18, k-58220 cultivar led to an increase in plant height ($r = 0.4$; $P = 0.03$).

The spike length increased with a growth in the seed projection perimeter and width (Kolkhoznitsa, k-30177: $r = 0.5$; $P = 0.02$; $r = 0.6$; $P = 0.03$, respectively) and a decrease in the seed projection maximum and interval brightness (Ester, k-64544: $r = 0.4$; $P = 0.03$; $r = 0.3$; $P = 0.04$, respectively).

The grains number per spike increased with a growth in the ellipse factor values (Kolkhoznitsa, k-30177 - $r = 0.4$; $P = 0.03$; Rostan', k-64391 - $r = 0.4$; $P = 0.04$) and decreased with an increase in the seeds roundness (Rostan', k-64391 - $r = -0.5$; $P = 0.01$).

The spikelets number per spike increased with a growth of length (Omskaya 18 k-58220 - $r = 0.6$; $P = 0.008$) and width of seeds (Saratovskaya 29, k-40599 - $r = 0.5$; $P = 0.03$) and reduction in the maximum brightness (Ester, k-64544 - $r = -0.7$; $P = 0.001$).

Plants of the Ester, k-64544 cultivar grew faster with decreasing of the brightness deviation, the maximum brightness, interval brightness of seed ($r = -0.4$; $P = 0.03$; $r = -0.7$; $P = 0.004$; $r = -0.4$; $P = 0.03$), while on cultivars Kolkhoznitsa, k-30177 - with decreasing the seeds elongation ($r = -0.4$; $P = 0.04$), Saratovskaya 29, k-40599 - with decreasing the integral brightness ($r = -0.5$; $P = 0.02$).

The total and productive bushiness of plants of the Ester, k-64544 cultivar decreased with a growth of maximum and integral brightness ($r = -0.6$; $P = 0.01$; $r = -0.4$; $P = 0.03$ and $r = -0.5$; $P = 0.03$; $r = -0.6$; $P = 0.02$, respectively). A decrease in the productive bushiness of the Leningradka, k-47882 cultivar with increasing of integral luminance was observed ($r = -0.5$; $P = 0.03$).

The flag leaf area of the HD 2329, k-58775 cultivar decreased with a growth of the roundness ($r = -0.6$; $P = 0.02$) and the optical density of seeds ($r = -0.4$; $P = 0.01$).

Wheat seeds can be both a direct source of infection during the growing season, and have an indirect effect on the complex of plants adaptive reactions to environmental factors, including resistance to diseases. The genes of plant defensins, which inhibit, in particular, the development of phytopathogenic micromycetes, are expressed in various plant organs, including seeds (Andersen et al., 2018). The powdery mildew development increased with a decrease in the seed projection width (Kolkhoznitsa, k-30177 - $r = -0.3$; $P = 0.04$), the average chord (Leningradskaya 97, k-62935 - $r = -0.5$; $P = 0.02$), the brightness deviation (Saratovskaya 29, k-40599 - $r = -0.6$; $P = 0.01$) and with an increase in the optical density of the seed projection (Saratovskaya 29, k-40599 – $r = 0.4$; $P = 0.02$), and in the integral brightness (Saratovskaya 29, k–40599 - $r = 0.6$; $P = 0.01$).

The brown rust development decreased with an increase in the seed ellipse factor (Saratovskaya 29, k-40599: $r = -0.5$; $P = 0.03$), roundness (Ester, k-64544: $r = -0.6$; $P = 0.01$) and with a decrease in the average brightness, brightness deviation, and integral brightness of seeds (HD 2329, k-58775 - $r = 0.7$; $P = 0.003$; $r = 0.5$; $P = 0.02$; $r = 0.4$; $P = 0.04$, respectively). The pathogen's pustules number increased on wheat leaves with an increase in average brightness, brightness deviation, and integral brightness (HD 2329, k-58775 - $r = 0.6$; $P = 0.04$; $r = 0.6$; $P = 0.01$; $r = 0.5$; $P = 0.03$; respectively) and decreased with an increase in the optical density of seeds (HD 2329, k-58775–$r = –0.7$; $P = 0.004$).

The equity distribution of positive and negative correlation coefficients that characterize the dependences between the wheat productivity indicators, the intensity of diseases development and the X-ray characteristics of wheat seeds were analysed during the experiment.

Positive correlations dominated in relation to the seed projection area and to 63.6% of wheat productivity indicators. The perimeter of the seed projection influenced on the increase and decrease of 45.4% of wheat productivity indicators. The wheat leaf blotch development in most cultivars increased with a growth of the indicator values, while powdery mildew and brown rust (according to the pustules number) - decreased. The dominant tendency was an increase in the values of 54.5% of wheat productivity indicators with an increase in the seeds length. The wheat leaf blotch development increased with a growth in the optical index values in 70% of cultivars, while brown rust and powdery mildew - decreased in 80% of cultivars.

A significant increase in the values of 81.8% of productivity indicators with an increase in the width of the seed projection was revealed. In particular, the wheat yield increased with a growth in the optical index in 60% of cultivars. The wheat leaf blotch development in most cultivars increased with a growth of the indicator values, while powdery mildew and brown rust (according to the pustules number) - decreased.

An increase of 63.6% of productivity indicators with a decrease in the values of the seed projection' average chord was observed. The wheat leaf blotch development in most cultivars increased with a growth of the indicator values, while powdery mildew and brown rust (according to the pustules number) - decreased. A predominantly inverse correlation between 54.5% of productivity indicators and the seed projection' elongation was found. The yield of 70% of cultivars decreased with an increase in the optical index value. The growth of the average size of the seed projection caused an increase in the values of 81.8% of productivity indicators. The yield of 70% of cultivars increased with a growth in the value of this optical indicator. The development of wheat diseases in most cultivars increased with increasing the indicator values.

A positive correlation was found between of 45.5% of productivity indicators and the values of the seed projection circle factor. An increase in wheat yield was observed in 70% of cultivars with a growth in the values of this optical indicator. The brown rust development decreased with an increase in the indicator of 60% of cultivars, and powdery mildew increased in 70% of cultivars. An increase in the values of the seed projection' circle factor caused an increase in 72.7% of productivity indicators. A tendency of increase the wheat biological yield with a growth in the optical index in 80% of wheat cultivars and an increase in plant damage by powdery mildew was revealed. An increase in the seed projection roundness led to a decrease of 45.5% of wheat productivity indicators. Besides this, negative correlations between this optical indicator and biological yield were found in 60% of cultivars. The degree of wheat powdery mildew damage decreased with an increase in the seed projection roundness, which was found in 60% of cultivars.

The prevailing tendency was a decrease of 54.5% of wheat productivity indicators with an increase in the average brightness of the seed projection. The wheat biological yield increased with a decrease in the values of the optical index, which was typical for 70% of the studied cultivars. The wheat leaf blotch and powdery mildew development increased with an increase in the average brightness of the seed projection. This dependence was typical for 80% of the studied cultivars.

The nature of the SD of the seed projection brightness dependence on the productivity indicators varied. Positive dependences prevailed in relation to the plant development phase, the flag leaf area and the spike weight, negative ones - to the plants height, the spike length. Wheat damage caused by leaf blotch and powdery mildew increased with a growth in the brightness of the seed projection, while by brown rust (by the pustules number) - decreased.

The growth of the minimum brightness of the seeds projection was accompanied by an increase of 36.3% of the productivity indicators: the productive bushiness (marked on 80% of cultivars), the total bushiness (marked 90% of cultivars), the spike length (noted on 60% of cultivars), the biological yield (noted by 60% of cultivars) while reduced of 45% of the indicators: the number of seedlings leaves, the plants height, the flag leaf area, the spikelets number per spike, the grains number per spike. The development of wheat leaf blotch and brown rust mainly increased with a growth in the minimum brightness of the seed projection, while powdery mildew decreased.

A predominantly inverse correlation between of 45.5% of productivity indicators and the maximum brightness of the seed projection was determined. The yield of 60% of cultivars decreased with an increase in the value of the optical index. The plants damage by leaf blotch mainly increased with a growth in the indicator, while by powdery mildew decreased.

For 72.7% of productivity indicators, inverse correlations with the integral brightness of the seed projection were marked. At the same time, a decrease in biological yield with an increase in the optical index was recorded in 70% of cultivars. The intensity of wheat affects by leaf blotch increased with a growth in the integral brightness of the seed projection, while by powdery mildew - decreased.

The predominance of positive correlations between the values of the integral brightness of the seed projection and of 45.4% of productivity indicators was noted. This dependence is also characteristic of the wheat biological yield, which increased in 60% of cultivars with a growth in the integral brightness of the seed projection. The brown rust and powdery mildew development decreased with an increase in the optical index, while leaf blotch increased.

CONCLUSIONS

The application of the latest achievements of biophysics, including instrumental methods of non - destructive testing of the structural and functional characteristics of seeds-gas - discharge imaging and soft-beam X-ray microscopy, was analyzed. Nonviable wheat seeds in compare to healthy (completed) differed mainly smaller area, shape factor, standard deviation (SD) of three-dimensional fractality along the isoline, entropy along the isoline, higher brightness and standard deviation of the gas discharge image (GDI) isoline radius. Morpho - and densitometric parameters of non-viable wheat seeds were characterized mainly by reduced values of the circle factor, roundness, minimum and maximum average brightness, but by greater elongation and optical density of the X-ray projection. Wheat seeds, which gave the seedlings, died later, had a smaller area, SD of three-dimensional fractality along the isoline, average radius of the isoline, entropy along the isoline, GDI isoline length, average chord and roundness of the radiographs projection, but greater values of ellipse factor of the projection radiographs. The revealed tendency of increase of most of the wheat productivity indicators with a reduction in area GDI, SD of the seeds GDI isoline radius, the chord average, elongation, the average brightness of the projection, the integral brightness of the projection and with the increase of entropy along the GDI isoline, the length of the GDI isoline, area, size, length and width of seeds, the factor of projection circle.

The intensity of wheat diseases varied depending on the structural and functional characteristics of wheat seeds.

In particular, it was noted, that the development of brown rust decreased with an increase in the entropy along the isoline, the contour irregularity and the average radius of the isoline. An increase in the values of the average GDI intensity, fractality along the contour, and irregularity of the seed contour led to a decrease in the intensity of powdery mildew development. The development of wheat leaf blotch increased with a decrease in the average radius of the isoline, the irregularity of the GDI contour, and an increase in the normalized SD of the isoline radius, the SD of fractality. The obtained data indicate the possibility of more effective cultivation and protection of soft wheat from diseases using a complex of introscopic methods for seed material assessment (microfocus radiography, gas-discharge visualization).

The experimental data indicate the possibility of more effective cultivation and protection of soft wheat in forecasting the biological usefulness of vegetative plants using the methods of microfocus radiography and gas discharge visualization of seed material.

As a result of the conducted research, the complex of indicators of the seeds gas-discharge glow, morphometric and optical parameters of their radiographs, which are an additional tool for the express assessment of the quality of seed material, has been identified. This information makes it possible to obtain a more complete description of the biological and economic suitability of the seed material, and, possibly, in the future, to predict the seeds field germination and potential yield, identify the main seeds defects, predict the development of diseases and possible changes in plant resistance to diseases.

The question of the relationship between the characteristics of gas-discharge glow with the indicators of plant bioproductivity and the mechanisms of a gas discharge formation when placing a seed in a high-intensity electromagnetic field still needs careful study with the involvement of scientists in the field of physics of living systems.

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